



Using the Vertical Land Movement estimates from the IGS TIGA combined solution to derive Global Mean Sea Level changes

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Overview:

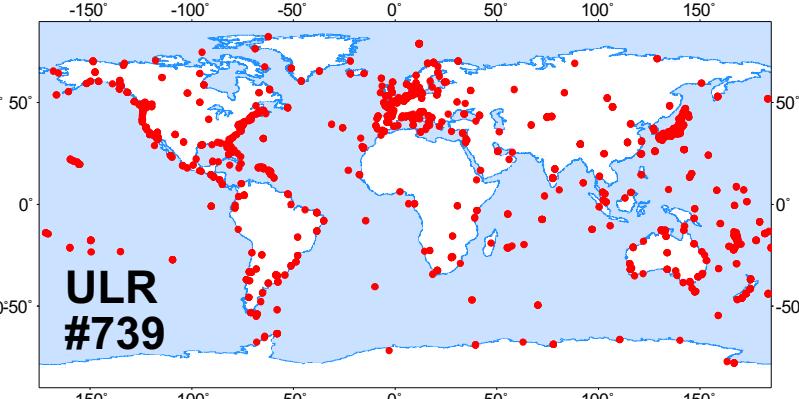
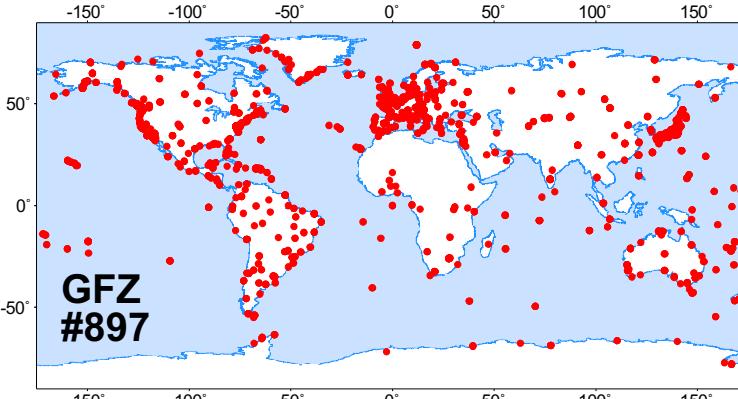
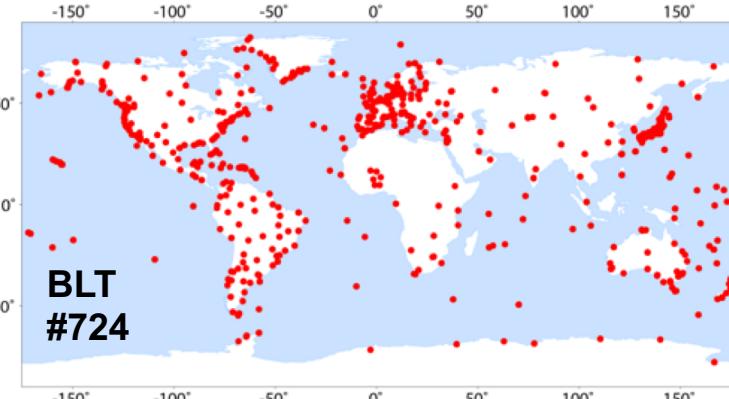
1. GPS-derived vertical land movement from TIGA combined solution
2. Analysis of the relative sea-level records
3. Correcting the relative sea-level records for vertical land movement
(GPS-observed vs GIA-predicted)
4. Reconstruction of absolute sea-level rise
5. Conclusions

TIGA combined solution:

Three independent GPS daily solutions (repro2) provided by:

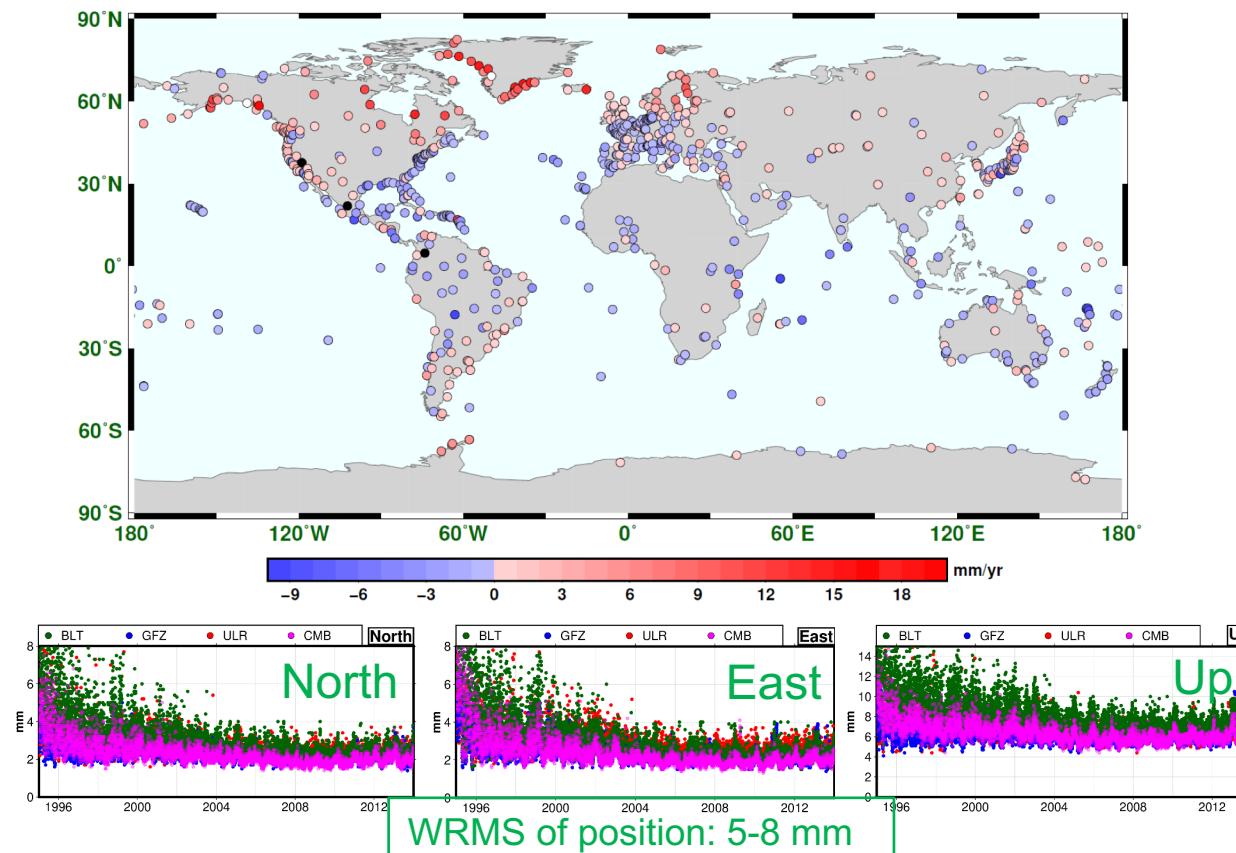
- BLT (British Isles continuous GNSS Facility – University of Luxembourg consortium): Bernese software,
- GFZ (GeoForschungsZentrum, Germany): EPOS P8 software,
- ULR (University of La Rochelle, France): GAMIT software

as part of their TIGA (Tide Gauge Benchmark Monitoring Group – Working Group of the International GNSS Service) activities have been used for this study.

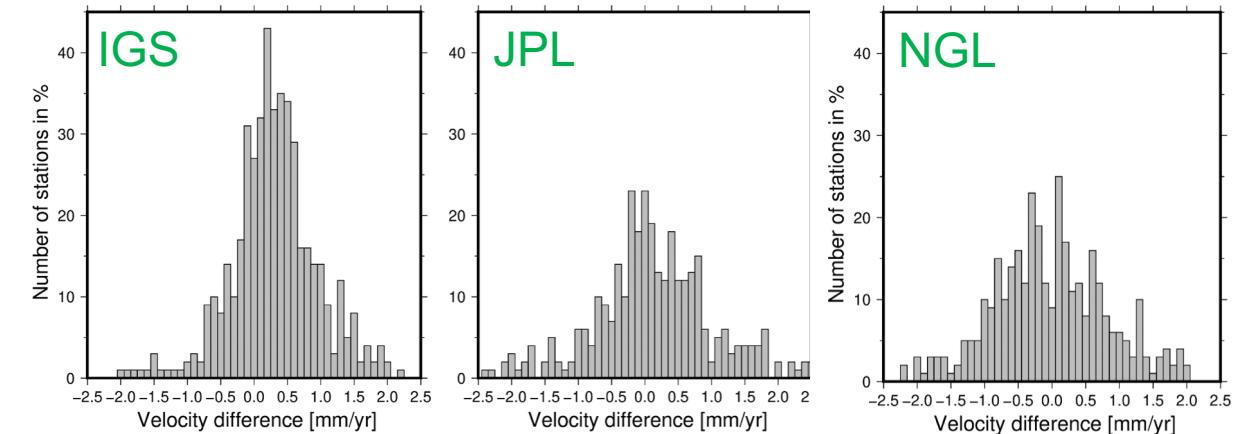


TIGA combined solution:

The combination has been performed at the University of Luxembourg using Combination and Analysis of Terrestrial Reference Frame (CATREF) software
– **815 stations** in total.



The distributions of velocity differences between the TIGA combination and solutions of:



Solution	No of common stations	RMS [mm/yr]	Bias [mm/yr]
IGS	465	0.7	0.2
JPL	326	1.0	0.1
NGL	460	1.1	0.1

Vertical Land Movement:

Extended trajectory model (Bevis and Brown, 2014):

multi-trend

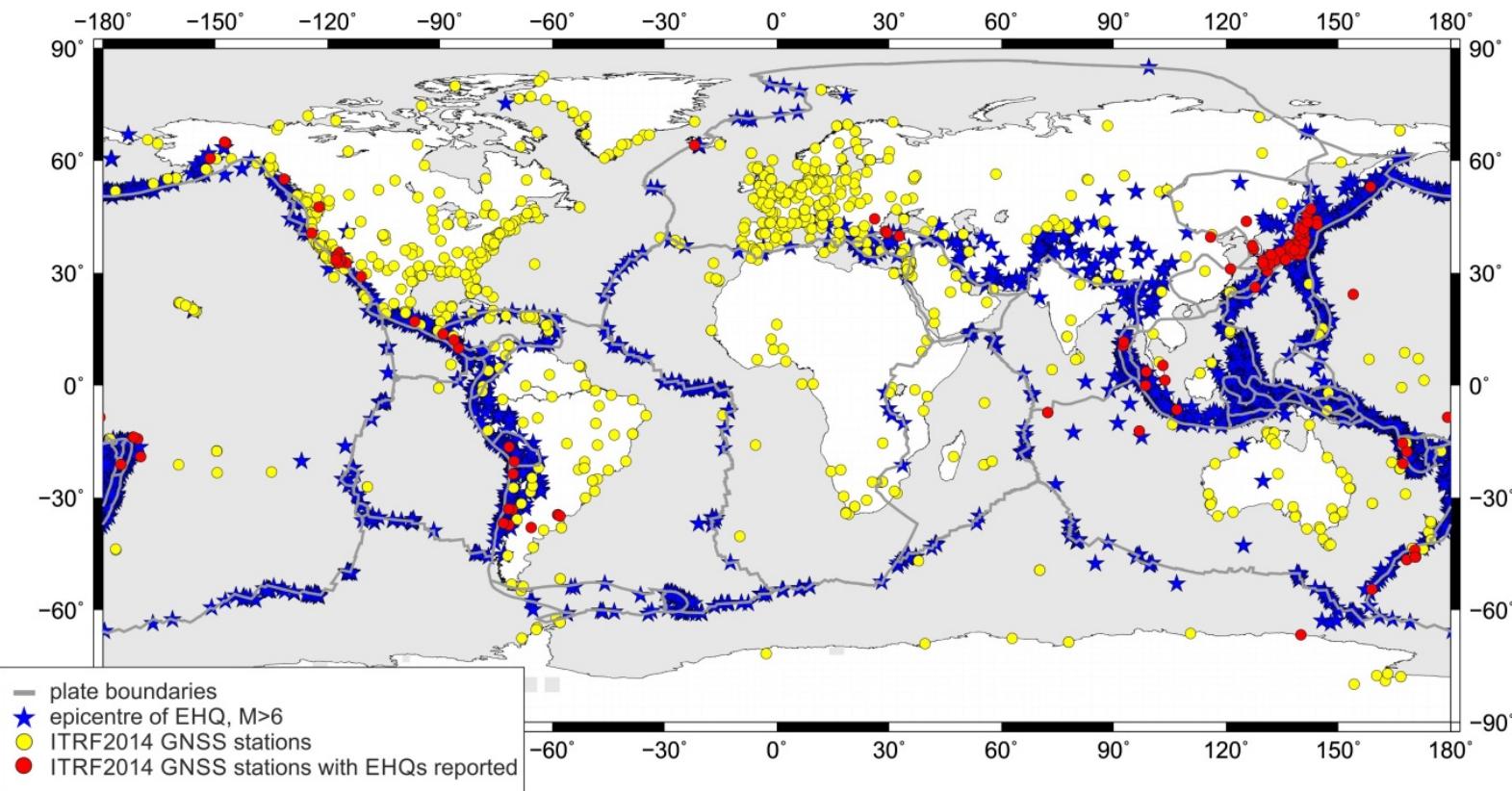
shift

$$\mathbf{X}(t) = \sum_{i=1}^k v_i \cdot t + \sum_{i=1}^n J_i \cdot H(t - t_j) + \\ + \sum_{i=1}^n [S_i \cdot \sin(\omega_i \cdot t) + C_i \cdot \cos(\omega_i \cdot t)] +$$

$$+ b \cdot \log\left(1 + \frac{t - t_0}{l_\tau}\right) + c \cdot \left[1 - \exp\left(-\frac{t - t_0}{e_\tau}\right)\right] + \varepsilon$$

arguments of post-seismic function of relaxation (ITRF2014)

time of EQ



TIGA combined solution: 99 out of 815 (12%)

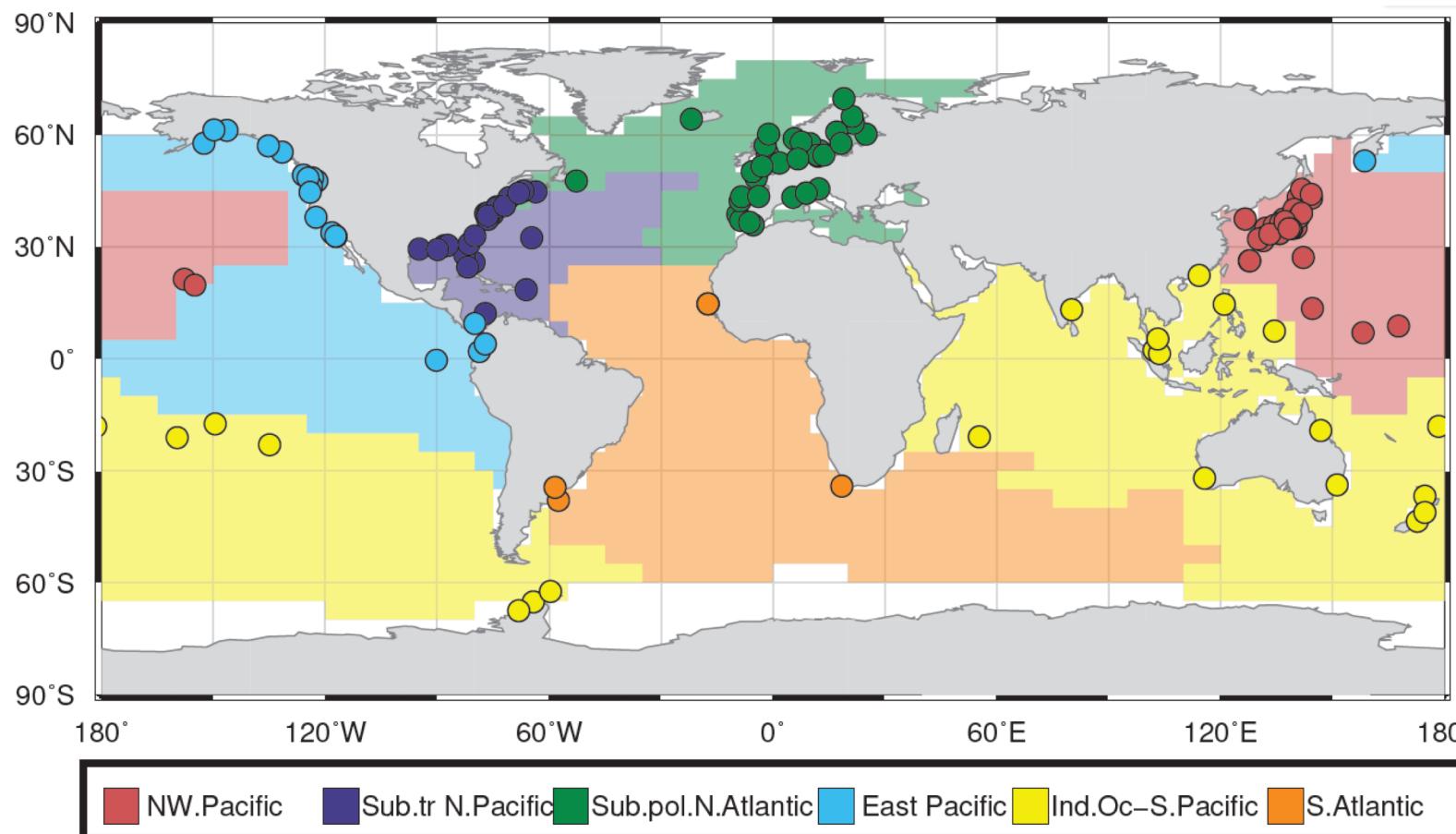
Klos A., Kusche J., Fenoglio-Marc L., Bos M.S., Bogusz J. (2019). Introducing a vertical land motion model for improving estimates of sea level rates derived from tide gauge records affected by earthquakes. GPS Solutions, 23:102, doi:10.1007/s10291-019-0896-1.

Tide gauge records (RSL):

Permanent Service for Mean Sea Level (PSMSL; Simon et al., 2013) Revised Local Reference (RLR) monthly-averaged time series (Holgate et al., 2013) – **158 stations** in total.

These include:

- 27 selected TG from Ray and Douglas (2011) and Douglas (1997) „gold standard”;
- 62 TG from Japanese seas.





Tide gauge records (RSL):

Deterministic model [days]:

$$RSL(t) = RSL_0 + \sum_{i=1}^2 v_i \cdot t + \boxed{\sum_{i=1}^{12} [S_i \cdot \sin(\omega_i \cdot t) + C_i \cdot \cos(\omega_i \cdot t)]} + \\ + a \cdot IB + b \cdot MWS + c \cdot ZWS + d \cdot PDO + e \cdot NPGO + f \cdot ENSO + \dots + \varepsilon$$

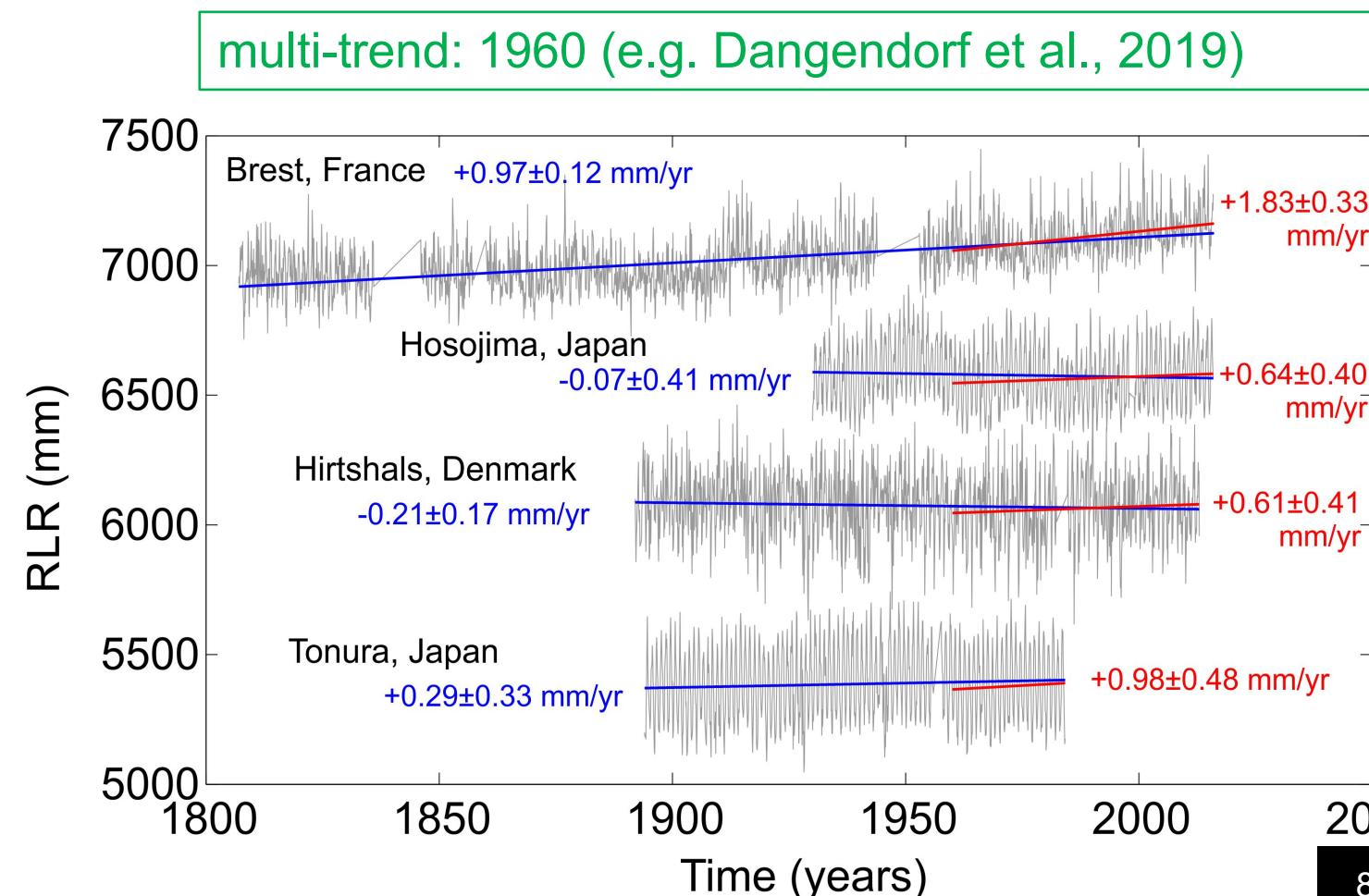
6793,65	1 cpn (nodal tide)
3396,82	2 cpn Woodworth, 2012)
2264,55	3 cpn
1698,41	4 cpn
431,00	1 cpC (Chandler)
215,50	2 cpC Trupin and Wahr, 1990)
143,67	3 cpC
107,75	4 cpC
365,25	1 cpy (tropical)
182,63	2 cpy
121,75	3 cpy
91,31	4 cpy

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Tide gauge records (RSL):

Geophysical effects:

- inverted barometer,
- meridional and zonal components of wind stress,
- Pacific Decadal Oscillation (PDO),
- North Pacific Gyre Oscillation (NPGO),
- ENSO,
- ...

$$RSL(t) = RSL_0 + \sum_{i=1}^2 v_i \cdot t + \sum_{i=1}^{12} [S_i \cdot \sin(\omega_i \cdot t) + C_i \cdot \cos(\omega_i \cdot t)] + \\ + a \cdot IB + b \cdot MWS + c \cdot ZWS + d \cdot PDO + e \cdot NPGO + f \cdot ENSO + \dots + \varepsilon$$

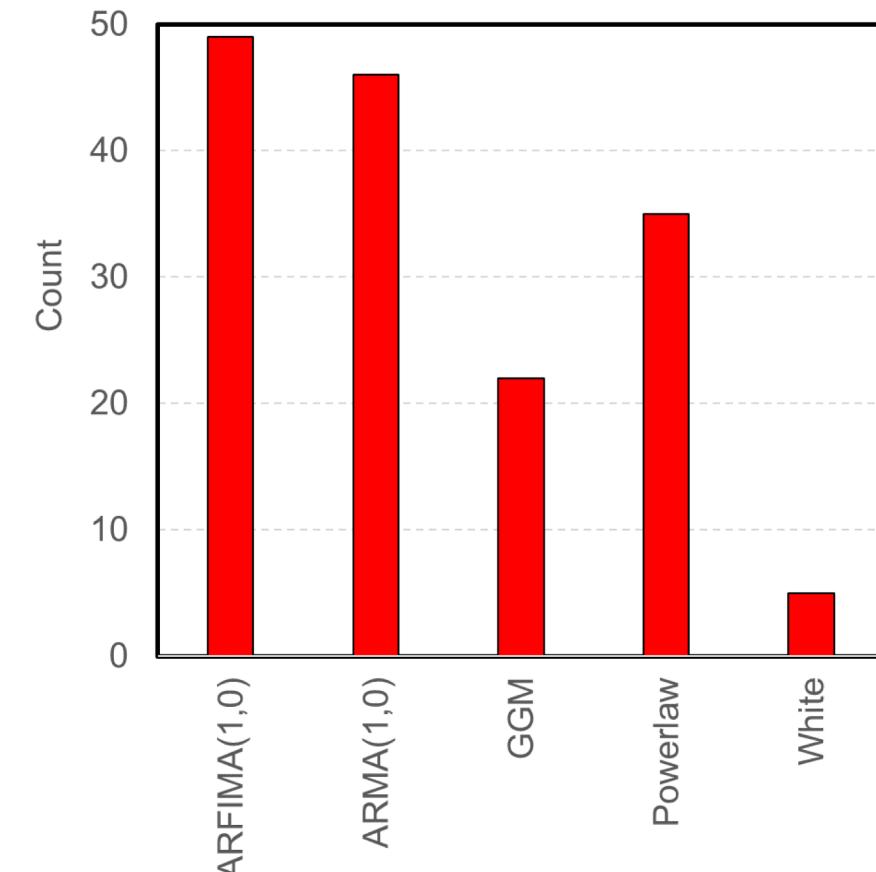
Their inclusions depends on the basin considered. Sea-level trends are affected below the 1-sigma significance level.

Multivariate regression analysis – Hector software (Bos et al., 2013).

Tide gauge records (RSL):

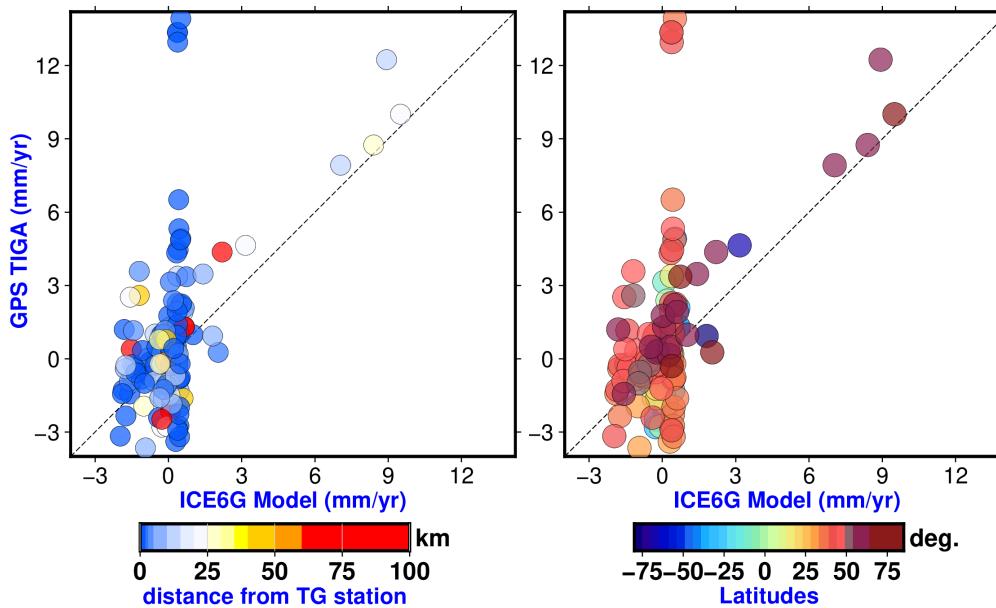
1. White
2. Power-law
3. Power-law+White
4. ARMA(1,0)
5. ARMA(1,0)+White
6. ARMA(5,5)+White
7. ARMA(5,0)+White
8. ARMA(1,1)+White
9. ARFIMA(5,d,5)+White
10. ARFIMA(1,d,0)+White
11. GGM
12. GGM+White (Bos et al., 2013; Royston et al. 2018)

$$RSL(t) = RSL_0 + \sum_{i=1}^2 v_i \cdot t + \sum_{i=1}^{12} [S_i \cdot \sin(\omega_i \cdot t) + C_i \cdot \cos(\omega_i \cdot t)] + \\ + a \cdot IB + b \cdot MWS + c \cdot ZWS + d \cdot PDO + e \cdot NPGO + f \cdot ENSO + \dots + \varepsilon$$

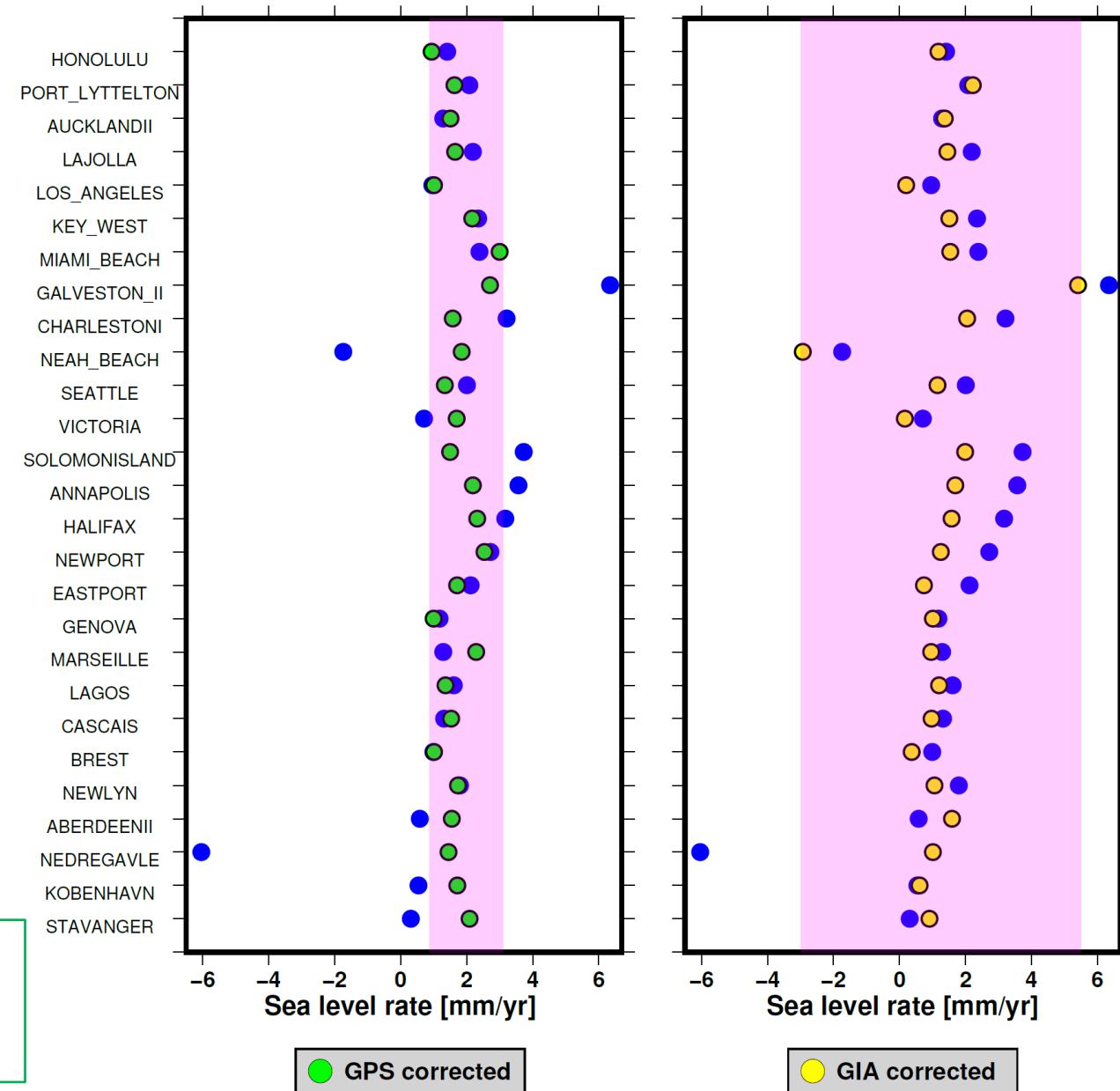


Tide gauge records (ASL):

TIGA combined solution and
Glacial Isostatic Adjustment (GIA):
ICE-6G_C (VM5a) (Peltier et al., 2015)



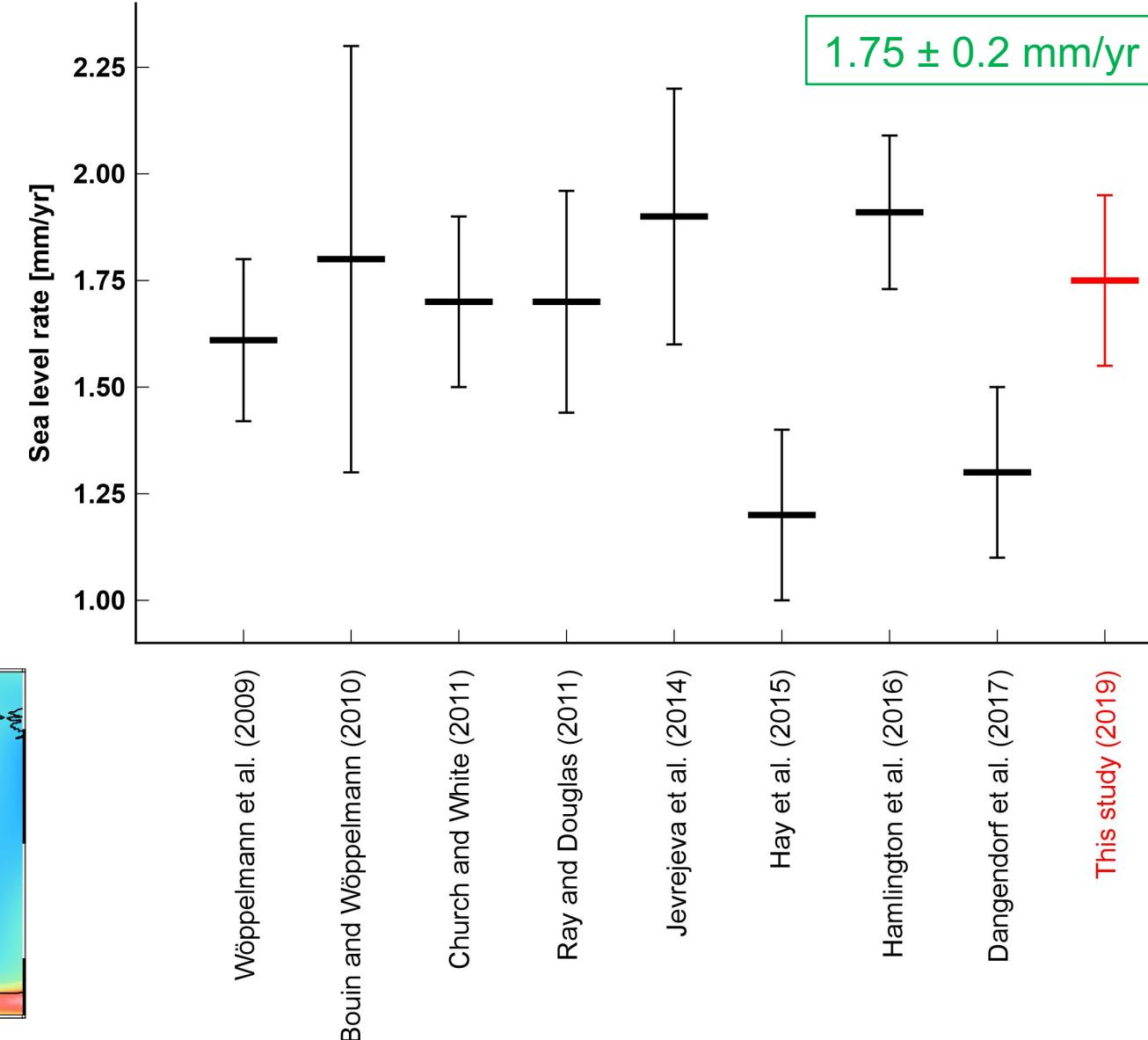
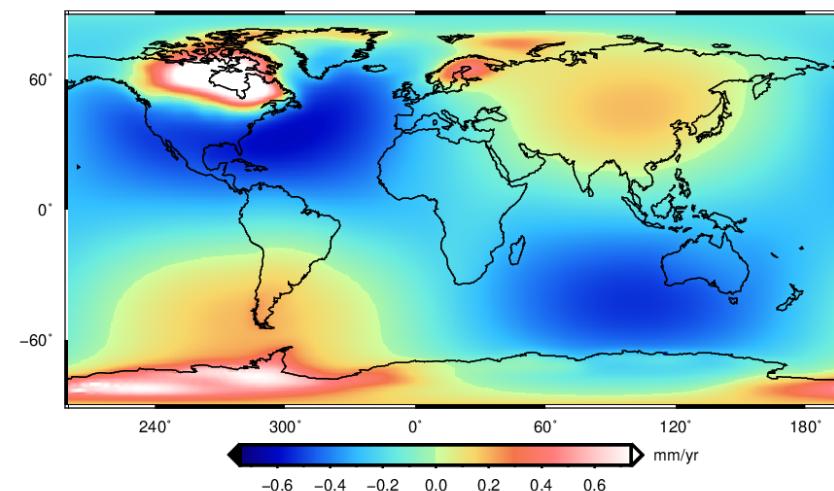
Distance and location dependency comparison between GPS corrected and GIA corrected 158 TG records. Correlation is higher in high latitudes.



This comparison is based on Douglas (1997) „gold standard“ TG records

Results:

	No corrections RSL:	VLM Corrections ASL:	
	TG trend [mm/yr]	TG+GIA trend [mm/yr]	TG+TIGA+ geoid rate trend [mm/yr]
Scatter of MSL trends	2.10	1.26	0.52



Conclusions:

1. TIGA combined solution is specially dedicated to compute VLM from GNSS
2. PPP or NS? Single or combined? CM or CF? Non-tidal effects?
3. Non-linear motion and interannual variations for sufficient correction of TG records?
4. Systematic errors of GNSSs – integration with other techniques like InSAR?
5. Considering of real stochastic properties

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